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THE PROCESSING TECHNIQUES AND BEHAVIOUR OF ALUMINUM METAL MATRIX WITH DIFFERENT REINFORCEMENT MATERIALS

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ABSTRACT

Improvement in the mechanical properties and retainment of properties is an essential requirement for the industrial application. The properties of the composite not only depend on reinforcement materials but it also depends on the manufacturing technique adopted for processing of the composites. This paper discusses various fabrication techniques of composite. This paper summarizes the various aluminium grades used in the industry and how its properties can be improved using different reinforcement materials like carbides, oxides, organic compounds and industrial agro waste. It reviews the influence of different reinforcement material on mechanical properties like hardness, tensile strength, density, and percentage elongation. This also paper reviews comprehensive data related to the research work carried with different various weight percentage reinforcement material.

***KEYWORDS:** Metalmatrix Composite, Industrial Waste, RHA & Casting*

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Original Article

INTRODUCTION

The industrial revolution has also led to the development of new materials in the automobile, aerospace and various processing industries. Composite are one among the developing materials due to its improved properties which satisfied the requirements of the various industries. Composites are made of several parts or element. Composite materials are defined as a material which is made of two or more materials at a microscopic scale and has chemically distinct phases. Composite materials can also be defined as the combination of two or more materials to enhance the properties of the parent material. The composite material constitutes of two materials viz. Reinforcing material and Matrix material. Properties of composite materials can be modified according to required final properties of a component or the product. Metal matrix composite (MMC), polymer matrix composite (PMC), ceramic matrix composite (CMC), and other inorganic composites are glass and carbon composite, these above composites are classified based on the matrix material used during processing of composite materials. Composites can also be classified based on the structure and geometry of reinforcement materials – dispersive composites, particulate composite and fibrous composite.

MMC are defined as the composite with at least two constituent materials with one being a metal and the other being metals, ceramics or organic compounds. The purpose of manufacturing of composites is not only

concerned to increase the firmness or strength, it also has to serve the various other purposes like improved temperature range, mechanical properties, abrasion resistance, dimensional stability and reduce specific weight compared with pure metal. The most widely used metal matrices, mainly for their price and variability. Aluminium alloys are most preferred material for engineering application due to its advantage of low weight and excellent thermal properties over other material [1]. Aluminium matrix composite is the most competitive composite in emerging industrial era. Aluminium matrix improves its properties when it is reinforced with hard ceramic materials like Al_2O_3, SiC, and B4C etc [2].

Properties of Matrix and Particles Reinforcements

Aluminium and its alloys have a excellent industrial applications due to its properties, however there are some of the drawbacks of the material can be overcome by addition of reinforcement material. Choosing of appropriate aluminium alloy with characteristic alloying elements for desired industrial application where the mechanical properties are taken into consideration [3]. The aluminium alloy composite materials have high strength, high stiffness, high thermal stability, more corrosion and wear resistance and high fatigue life hence aluminium has found to be best alternative for industrial applications [4]. The property of MMC mainly depends on the processing method adopted for producing the composites. Aluminium alloys are normally identified by a four figure system which is now universally accepted. Table 1 describes the designation for aluminium wrought alloys.

Table 1: Designation of Aluminium Alloys

Designation	Principle Element
1xxx	Unalloyed (Pure)
2xxx	Copper
3xxx	Manganese
4xxx	Silicon
5xxx	Magnesium
6xxx	Magnesium+ Silicon
7xxx	Zinc
8xxx	Lithium/Tin

Oxides, carbides and other organic compounds can be used as reinforcement materials in the metal matrix composites. Reinforcement particle changes the structural and mechanical properties of the matrix material. The most commonly used reinforcement materials are listed in table 2. Selection of reinforcement materials mainly depends on the required properties for industrial application. For operation like toughening mechanisms, the microstructure should be homogeneous; it means the metal particles should be uniformly distributed in the ceramic particles [5].

Table 2: Reinforcement Materials and its Properties

Reinforcement	Melting	Density	Hardness
		Point °Cg/cm^3	Gpa
SiC	2730	3.21	32.0
B_4C	3500	2.52	38.0
TiC	3250	4.93	31.4
Al_2O_3	2045	3.97	20.7
TiB_2	2980	4.52	25.0
Si_3N_4	1900	3.17	15.5

Apart from oxides, carbides and other compounds industrial agro wastes can also be used as reinforcement material in the manufacturing of MMC. Fly ash, red mud, palm oil clinker, rice husk ash, coconut shell and sugarcane bagasse are some of the examples of industrial agro waste material [6]. The chemical compositions of some of the

industrial waste are listed in the tables 3-7.

Table 3: Chemical Composition of Fly Ash [7]

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Carbon/LOI
56.92	29.9	8.44	2.75	1.99

Table 4: Chemical Composition of Bagasse Ash [8]

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Others	LOI
77.29	10.95	3.66	2.09	1.49	0.49	3.16	0.38	Balance	3.28

Table 5: Chemical Composition of Coconut Shell Ash [9]

SiO_2	MgO	Al_2O_3	Fe_2O_3	CaO	K_2O	Na_2O	ZnO	MnO
45.05	16.2	15.6	12.4	0.57	0.52	0.45	0.3	0.22

Table 6: Chemical Composition of Palm Oil Clinker [10]

SiO_2	Fe_2O_3	K_2O	Al_2O_3	CaO	MgO	P_2O_5	TiO_2	Na_2O
81.8	5.18	4.66	3.5	2.3	1.24	0.76	0.17	0.14

Table 7: Chemical Composition of Rice Husk Ash [11]

SiO_2	Al_2O_3	MgO	Fe_2O_3	K_2O	SO_3	Na_2O	CaO	LOI	Others
97.095	1.135	0.825	0.316	0.181	0.146	0.092	0.073	0.965	Balance

Manufacturing Techniques

The property of MMC not only depends on the type of reinforcement but it also mainly depends on the manufacturing technique adopted for producing the composites. The manufacturing technique plays an important role in improving the physical appearance and developing different mechanical properties of the composite. The manufacturing techniques of the composite are classified based on the nature and behaviour of raw material. The various techniques for processing a composites are-

- Stir casting
- Friction stir processing
- Squeeze casting
- Chemical vapour deposition
- Physical vapour deposition
- In-situ fabrication technique
- Powder metallurgy

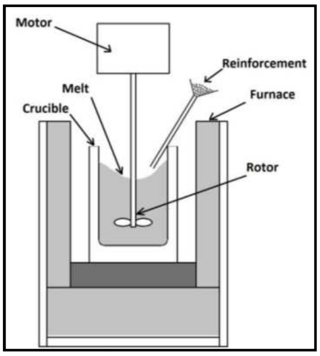

Figure 1: Stir Casting

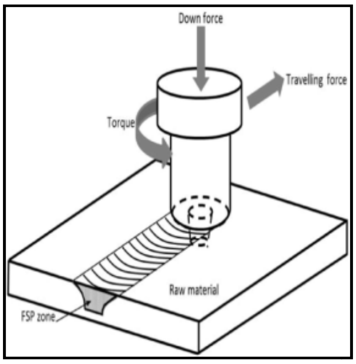

Figure 2: Friction Stir Processing

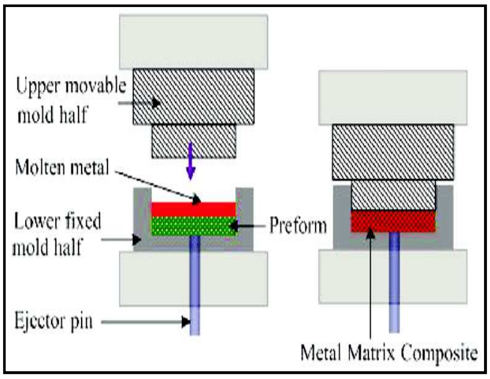

Figure 3: Squeeze Casting

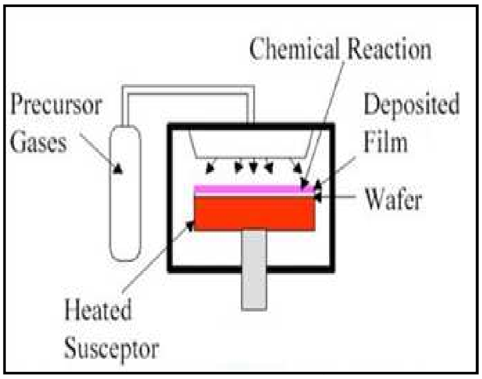

Figure 4: Chemical Vapour Deposition

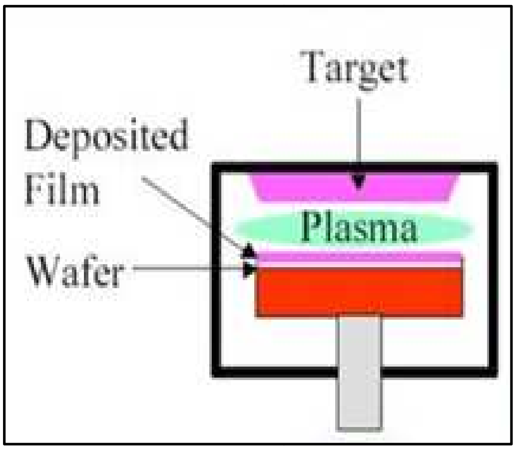

Figure 5: Physical Vapour Deposition

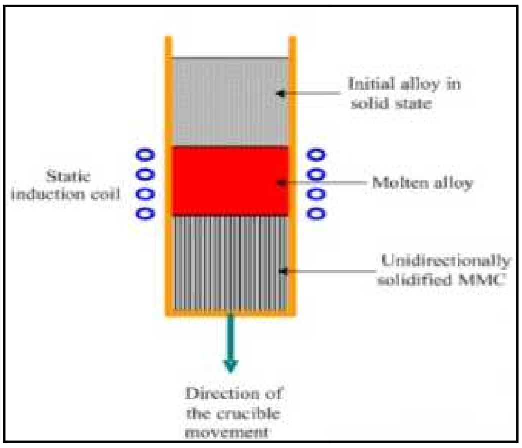

Figure 6: In-Situ Fabrication Technique

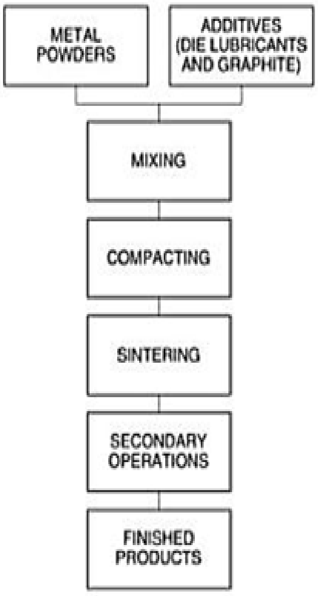

Figure 7: Powder Metallurgy

Influence of Reinforcement on MMC's

The different reinforcement materials used in developing the metal matrix are carbides, oxides, organic compounds, industrial agro waste and so on. The properties of reinforcement also play an important role in deciding the property of the composite along with manufacturing technique used. The different factors such as density, hardness, tensile test, and percentage elongation are considered in the study of various reinforcement materials for developing the composites. Present paper mainly focuses on the stir casting technique for manufacturing of composite.

Gaurav A et, al. [38] did a comparative study of AA6351 reinforced with SiC/RHA the results showed that the density of the composite increased with the increased content of SiC while with the increase in content of RHA the density of composite decreased. The micro hardness of the composite with SiC and RHA as reinforcement increased from 52.82 VHN to 72.5 and 61.3 VHN respectively for 8% reinforcement; this is due to uniform distribution of reinforcement in the matrix melt & dislocation density. The presence of hard particles in the in the reinforcement transferring of load from matrix to reinforcement has improved the tensile strength of the composite developed. S Nayaket, al. [39] studied tensile and hardness characterization for the composite, lower the percentage of zirconia higher the tensile strength and lowers the hardness value of the composite. PB Pawaret,al. [4] studied the hardness value of silicon carbide particle based aluminium composite and found highest hardness value of 60.3 BHN for 10% SiC reinforcement which is better than the aluminium metal. P Ashwathet, al. [40] evaluated the property of Al 2xxx with Al_2O_3 and SiC, alumina as reflected the better mechanical properties when compared with SiC. Table 8 gives the various different reinforcement aluminium metal matrix and its behaviour with and without reinforcement.

CONCLUSIONS

This paper presents the various aspects regarding the manufacturing of metal matrix by stir casting with different combination of reinforcement materials used in synthesis of MMC or Hybrid MMC and how it influences the mechanical properties has been reviewed. This paper also focuses on the use of industrial Agro waste as reinforcement material and its influence on the properties of the matrix material for manufacturing of the green composite. The data results showed that

with the addition of the agro waste as reinforcement material the mechanical properties like tensile strength, hardness has been increased and the weight of the prepared composite has been reduced due to less density of the reinforcement material. This paper provides the future scope for the researcher to study the behaviour of the reinforcement material on different grades of aluminium matrix composites.

Table 8: Properties of MMC with Different Reinforcement Materials

Composition	Fabrication Technique	Hardness	Tensile/Yield	Density	% Elongation	References
Al6082	Stir casting	31.6 BHN	161.5 MPa	2.69 g/cm³	8.6	[12]
Al6082 + 3wt. % Gr		31.0 BHN	160.0 MPa	2.67 g/cm³	8.0	
Al6082 + 6wt. % Gr		30.2 BHN	158.0 MPa	2.64 g/cm³	7.4	
Al6082 + 9wt. % Gr		29.0 BHN	155.0 MPa	2.62 g/cm³	7.0	
Al6082 + 12wt. % Gr		28.3 BHN	152.0 MPa	2.58 g/cm³	6.8	
Al6061 + 5wt.%SiC	Stir casting		132.3 MPa	2.70 g/cm³		[13]
Al6061 + 10wt.%SiC			143.4 MPa	2.71 g/cm³		
Al6061 + 15wt.%SiC			150.9 MPa	2.73 g/cm³		
Al6061 + 5wt.%SiC/Gr			144.7 MPa	2.66 g/cm³		
Al6061 + 10wt.%SiC/Gr			173.3 MPa	2.64 g/cm³		
Al6061 + 15wt.%SiC/Gr			192.4 MPa	2.63 g/cm³		
Al7075 + 2wt.% Ash +1wt.% Gr	Stir casting	87.3 BHN	259.3 MPa		6.7	[16]
Al7075 + 2wt.% Ash +3wt.% Gr		92.4 BHN	265.4 MPa		6.4	
Al7075 + 2wt.% Ash +5wt.% Gr		94.3 BHN	272.3 MPa		5.8	
Al7075 + 4wt.% Ash +1wt.% Gr		87.3 BHN	267.3 MPa		6.3	
Al7075 + 4wt.% Ash +3wt.% Gr		94.2 BHN	283.4 MPa		5.9	
Al7075 + 4wt.% Ash +5wt.% Gr		95.4 BHN	290.3 MPa		5.2	
Al7075 + 6wt.% Ash +1wt.% Gr		88.3 BHN	294.2 MPa		5.9	
Al7075 + 6wt.% Ash +3wt.% Gr		95.4 BHN	296.3 MPa		5.4	
Al7075 + 6wt.% Ash +5wt.% Gr		99.6 BHN	299.4 MPa		4.9	
Al6061+ 2wt.% MoS_2 + 4wt.% Al_2O_3	Stir casting	94.5 BHN	201.5 N/mm²			[14]
Al6061+ 2wt.% MoS_2 + 8wt.% Al_2O_3		98.0 BHN	221.4 N/mm²			
Al6061+ 2wt.% MoS_2 + 12wt.% Al_2O_3		106.23 BHN	243.4 N/mm²			
Al6061+ 4wt.% MoS_2 + 4wt.% Al_2O_3		96.7 BHN	219.7 N/mm²			
Al6061+ 4wt.% MoS_2 + 8wt.% Al_2O_3		104.7 BHN	237.2 N/mm²			
Al6061+ 4wt.% MoS_2 + 12wt.% Al_2O_3		107.5 BHN	259.5 N/mm²			
Al6061+ 8wt.% MoS_2 + 4wt.% Al_2O_3		97.37 BHN	207.4 N/mm²			
Al6061+ 8wt.% MoS_2 + 8wt.% Al_2O_3		103.2 BHN	227.8 N/mm²			
Al6061+ 8wt.% MoS_2 + 12wt.% Al_2O_3		104.5 BHN	251.3 N/mm²			

Composition References	**Fabrication**	**Hardness**	**Tensile/Yield**	**Density**	**%**	
	Technique				**elongation**	
AA6082	Stir casting	49.5 VHN	2.69 g/cm^3			[15]
AA6082 + 3wt.% Si_3N_4		82.0 VHN	2.70 g/cm^3			
AA6082 + 6wt.% Si_3N_4		86.0 VHN	2.72 g/cm^3			
AA6082 + 9wt.% Si_3N_4		91.0 VHN	2.74 g/cm^3			
AA6082 + 12wt.% Si_3N_4		93.5 VHN	2.75 g/cm^3			
Al7075	Stir casting		157 N/mm^2			[17]
Al7075 + 1wt.% B_4C			250 N/mm^2			
Al7075 + 2wt.% B_4C			255 N/mm^2			
Al7075 + 3wt.% B_4C			270 N/mm^2			
Al7075 + 4wt.% B_4C			285 N/mm^2			
Al2024	Hot-extrusion		489 MPa		14.7	[18]
Al2024 + 10vol.% B_4C			573.5 MPa		1.71	
Al2024 + 20vol.% B_4C			626.7 MPa		1.64	
Al7075+3%B_4C+3%Gr+6%fly ash	Stir casting	140 BHN				[19]
Al7075+3%B_4C+4%Gr+7%fly ash		162 BHN				
Al7075+3%B_4C+3%Gr+6%fly ash		172 BHN				
LM25	Stir casting	37.8 BHN	64.24 MPa		4.00	[20]
LM25 + 3wt.% B_4C + 2wt.% Al_2O_3		52.8 BHN	51.75 MPa		3.71	
LM25 + 2wt.% B_4C + 3wt.% Al_2O_3		48.5 BHN	54.60 MPa		4.00	
Al + 5wt.% B_4C	Powder metallurgy	112.8 BHN	371 MPa			[21]
Al + 10wt.% B_4C		138.9 BHN	433 MPa			
Al + 15wt.% B_4C		167.6 BHN	485 MPa			
Al2024	Stir casting	80 BHN 236 N/mm^2	2.60 g/cm^3		19.4	[22]
Al2024 + 5% SiC		85 BHN 248 N/mm^2	2.40 g/cm^3		19.0	
Al2024 + 10% SiC		87 BHN 265 N/mm^2	2.30 g/cm^3		18.2	
Al2024 + 5% FA		80 BHN 245 N/mm^2	2.40 g/cm^3		16.3	
Al2024 + 10% FA		83 BHN 263 N/mm^2	2.20 g/cm^3		15.8	
Al2024 + 5% SiC + 5% FA		88 BHN 276 N/mm^2	2.20 g/cm^3		14.4	
Al2024 + 5% SiC + 10% FA		90 BHN 278 N/mm^2	2.10 g/cm^3		13.8	
Al2024 + 10% SiC + 5% FA		93 BHN 285 N/mm^2	2.10 g/cm^3		12.8	
A2024 + 10% SiC + 10% FA		95 BHN 293 N/mm^2	2.00 g/cm^3		11.9	

Composition References	**Fabrication**	**Hardness**	**Tensile/Yield**	**Density**	**%**	
	Technique				**Elongation**	
Al6082	Stir casting	31.6 BHN	161.5 MPa	2.69 g/cm^3	8.6	[12]
Al6082 + 3wt. % Gr		31.0 BHN	160.0 MPa	2.67 g/cm^3	8.0	
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Al6082 + 9wt. % Gr		29.0 BHN	155.0 MPa	2.62 g/cm^3	7.0	
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Al6061 + 5wt.%SiC	Stir casting		132.3 MPa	2.70 g/cm^3		[13]
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Al6061 + 15wt.%SiC/Gr			192.4 MPa	2.63 g/cm^3		
Al7075 + 2wt.% Ash +1wt.% Gr	Stir casting	87.3 BHN	259.3 MPa		6.7	[16]
Al7075 + 2wt.% Ash +3wt.% Gr		92.4 BHN	265.4 MPa		6.4	
Al7075 + 2wt.% Ash +5wt.% Gr		94.3 BHN	272.3 MPa		5.8	
Al7075 + 4wt.% Ash +1wt.% Gr		87.3 BHN	267.3 MPa		6.3	
Al7075 + 4wt.% Ash +3wt.% Gr		94.2 BHN	283.4 MPa		5.9	
Al7075 + 4wt.% Ash +5wt.% Gr		95.4 BHN	290.3 MPa		5.2	
Al7075 + 6wt.% Ash +1wt.% Gr		88.3 BHN	294.2 MPa		5.9	
Al7075 + 6wt.% Ash +3wt.% Gr		95.4 BHN	296.3 MPa		5.4	
Al7075 + 6wt.% Ash +5wt.% Gr		99.6 BHN	299.4 MPa		4.9	
Al6061+ 2wt.% MoS_2 + 4wt.% Al_2O_3	Stir casting	94.5 BHN	201.5 N/mm^2			[14]
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Al6061+ 2wt.% MoS_2 + 12wt.% Al_2O_3		106.23 BHN	243.4 N/mm^2			
Al6061+ 4wt.% MoS_2 + 4wt.% Al_2O_3		96.7 BHN	219.7 N/mm^2			
Al6061+ 4wt.% MoS_2 + 8wt.% Al_2O_3		104.7 BHN	237.2 N/mm^2			
Al6061+ 4wt.% MoS_2 + 12wt.% Al_2O_3		107.5 BHN	259.5 N/mm^2			
Al6061+ 8wt.% MoS_2 + 4wt.% Al_2O_3		97.37 BHN	207.4 N/mm^2			
Al6061+ 8wt.% MoS_2 + 8wt.% Al_2O_3		103.2 BHN	227.8 N/mm^2			
Al6061+ 8wt.% MoS_2 + 12wt.% Al_2O_3		104.5 BHN	251.3 N/mm^2			

Composition	Fabrication Technique	Hardness	Tensile/Yield	Density	% elongation	References
AA6082	Stir casting	49.5 VHN		2.69 g/cm^3		[15]
AA6082 + 3wt.% Si_3N_4		82.0 VHN		2.70 g/cm^3		
AA6082 + 6wt.% Si_3N_4		86.0 VHN		2.72 g/cm^3		
AA6082 + 9wt.% Si_3N_4		91.0 VHN		2.74 g/cm^3		
AA6082 + 12wt.% Si_3N_4		93.5 VHN		2.75 g/cm^3		
Al7075	Stir casting		157 N/mm^2			[17]
Al7075 + 1wt.% B_4C			250 N/mm^2			
Al7075 + 2wt.% B_4C			255 N/mm^2			
Al7075 + 3wt.% B_4C			270 N/mm^2			
Al7075 + 4wt.% B_4C			285 N/mm^2			
Al2024	Hot-extrusion		489 MPa		14.7	[18]
Al2024 + 10vol.% B_4C			573.5 MPa		1.71	
Al2024 + 20vol.% B_4C			626.7 MPa		1.64	
Al7075+3%B_4C+3%Gr+6%fly ash	Stir casting	140 BHN				[19]
Al7075+3%B_4C+4%Gr+7%fly ash		162 BHN				
Al7075+3%B_4C+3%Gr+6%fly ash		172 BHN				
LM25	Stir casting	37.8 BHN	64.24 MPa		4.00	[20]
LM25 + 3wt.% B_4C + 2wt.% Al_2O_3		52.8 BHN	51.75 MPa		3.71	
LM25 + 2wt.% B_4C + 3wt.% Al_2O_3		48.5 BHN	54.60 MPa		4.00	
Al + 5wt.% B_4C	Powder metallurgy	112.8 BHN	371 MPa			[21]
Al + 10wt.% B_4C		138.9 BHN	433 MPa			
Al + 15wt.% B_4C		167.6 BHN	485 MPa			
Al2024	Stir casting	80 BHN	236 N/mm^2	2.60 g/cm^3	19.4	[22]
Al2024 + 5% SiC		85 BHN	248 N/mm^2	2.40 g/cm^3	19.0	
Al2024 + 10% SiC		87 BHN	265 N/mm^2	2.30 g/cm^3	18.2	
Al2024 + 5% FA		80 BHN	245 N/mm^2	2.40 g/cm^3	16.3	
Al2024 + 10% FA		83 BHN	263 N/mm^2	2.20 g/cm^3	15.8	
Al2024 + 5% SiC + 5% FA		88 BHN	276 N/mm^2	2.20 g/cm^3	14.4	
Al2024 + 5% SiC + 10% FA		90 BHN	278 N/mm^2	2.10 g/cm^3	13.8	
Al2024 + 10% SiC + 5% FA		93 BHN	285 N/mm^2	2.10 g/cm^3	12.8	
A2024 + 10% SiC + 10% FA		95 BHN	293 N/mm^2	2.00 g/cm^3	11.9	

Composition	Fabrication Technique	Hardness	Tensile/Yield	Density	% Elongation	References
Al356	Stir casting	70 BHN	234 N/mm^2	2.60 g/cm^3	3.5	[23]
Al356 + 10% SiC		100 BHN	146 N/mm^2	3.00 g/cm^3		
Al356 + 10% SiC + 3% Mica		115 BHN	150 N/mm^2	3.10 g/cm^3		
Al356 + 10% SiC + 6% Mica		110 BHN	148 N/mm^2	3.16 g/cm^3		
Al-Mg-Si	Stir casting	67 BHN		2.81 g/cm^3		[24]
Al-Mg-Si + 10% SiC		77 BHN	155 N/mm^2	2.74 g/cm^3	23.0	
Al-Mg-Si + 2% BLA + 8% SiC		74 BHN	146 N/mm^2	2.69 g/cm^3	16.0	
Al-Mg-Si + 3% BLA + 7% SiC		72 BHN	138 N/mm^2	2.66 g/cm^3	14.0	
Al-Mg-Si + 4% BLA + 6% SiC		67 BHA	125 N/mm^2	2.64 g/cm^3	12.0	
Al-Mg-Si	Stir casting	67 BHN		2.81 g/cm^3		[25]
Al-Mg-Si + 10% Al_2O_3		75 BHN	120 N/mm^2	2.79 g/cm^3	12.0	
Al-Mg-Si + 2% RHA + 8% Al_2O_3		69 BHN	110 N/mm^2	2.68 g/cm^3	12.0	
Al-Mg-Si + 3% RHA + 7% Al_2O_3		66 BHN	106 N/mm^2	2.66 g/cm^3	10.0	
Al-Mg-Si + 4% RHA + 6% Al_2O_3		64 BHN	102 N/mm^2	2.62 g/cm^3	8.0	
A356	Stir casting	68 BHN	263 N/mm^2	2.73 g/cm^3	7.35	[26]
A356 + 2% SiC + 2% RHA		74 BHN	296 N/mm^2	2.70 g/cm^3	6.25	
A356 + 4% SiC + 4% RHA		83 BHN	310 N/mm^2	2.69 g/cm^3	5.6	
A356 + 6% SiC + 6% RHA		96 BHN	333 N/mm^2	2.69 g/cm^3	5.15	
A356 + 8% SiC + 8% RHA		104 BHN	356 N/mm^2	2.66 g/cm^3	4.9	
Al7075	Stir casting	67 BHN				[27]
Al7075 + 3% B_4C		77 BHN				
Al7075 + 3% B_4C + 5% SiC		82 BHN				
Al7075 + 3% B_4C + 10% SiC		85 BHN				
Al7075 + 3% B_4C + 15% SiC		88 BHN				
AZ91D	Die casting	65 BHN	199 MPa	1.81 g/cm^3		[28]
AZ91D + 5% FA		70.5 BHN	215 MPa	1.75 g/cm^3		
AZ91D + 10% FA		67.5 BHN	208 MPa	1.75 g/cm^3		
AZ91D + 15% FA		67.4 BHN	210 MPa	1.75 g/cm^3		
Al	Stir casting	70.4 BHN	164 MPa	2.84 g/cm^3		[8]
Al + 5% BA		73.6 BHN	174 MPa	2.67 g/cm^3		
Al + 10% BA		77.5 BHN	176 MPa	2.60 g/cm^3		
Al + 15% BA		84.7 BHN	150 MPa	2.54 g/cm^3		
Al + 20% BA		90.7 BHN	144 MPa	2.46 g/cm^3		

Composition References	Fabrication Technique	Hardness	Tensile/Yield	Density	% Elongation
Al + 25% BA		82.5 BHN	142 MPa	2.38 g/cm^3	
Al + 30% BA		75.0 BHN	139MPa	2.29 g/cm^3	
A356	Stir casting	65 BHN	165 MPa	2.66 g/cm^3	[29]
A356 + 6% FA		67 BHN	194 MPa	2.61 g/cm^3	
A356 + 12% FA		75 BHN	145 MPa	2.44 g/cm^3	
Al-4.5%Cu	Stir casting	81 BHN		2.75 g/cm^3	[30]
Al-4.5%Cu + 5% FA		83.2 BHN		2.71 g/cm^3	
Al-4.5%Cu + 10% FA		85.6 BHN		2.70 g/cm^3	
Al-4.5%Cu + 15% FA		86.1 BHN		2.64 g/cm^3	
Al-Si-Fe	Stir casting	63 BHN		2.85 g/cm^3	[31]
Al-Si-Fe + 3% CSA		67 BHN		2.83 g/cm^3	
Al-Si-Fe + 6% CSA		68 BHN		2.75 g/cm^3	
Al-Si-Fe + 9% CSA		70 BHN		2.70 g/cm^3	
Al-Si-Fe + 12% CSA		75 BHN		2.68 g/cm^3	
Al-Si-Fe + 15% CSA		77 BHN		2.66 g/cm^3	
A356.2	Vortex method	69 BHN		2.76 g/cm^3	[32,33]
A356.2 + 2% RHA		70 BHN		2.72 g/cm^3	
A356.2 + 4% RHA		72 BHN		2.69 g/cm^3	
A356.2 + 6% RHA		79 BHN		2.61 g/cm^3	
A356.2 + 8% RHA		81 BHN		2.57 g/cm^3	
Al-Si	Stir casting	65.3 BHN	255.6 MPa	2.62 g/cm^3	[34]
Al-Si + 5% FA		69.5 BHN	273.5 MPa	2.03 g/cm^3	
Al-Si + 10% FA		72.1 BHN	280.4 MPa	1.88 g/cm^3	
Al-Si + 15% FA		74.8 BHN	305.8 MPa	1.61 g/cm^3	
Al-Mg-Si + 10% SiC	Stir casting	93 BHN	185 MPa	2.72 g/cm^3	[35]
Al-Mg-Si + 1% CCA + 9% SiC		91 BHN	181 MPa	2.68 g/cm^3	
Al-Mg-Si + 2% CCA + 8% SiC		90 BHN	174 MPa	2.63 g/cm^3	
Al-Mg-Si + 3% CCA + 7% SiC		86 BHN	170 MPa	2.62 g/cm^3	
Al-Mg-Si + 4% CCA + 6% SiC		81 BHN	162 MPa	2.59 g/cm^3	
Al6082	Stir casting	31.6 BHN			
Al6082 + 3wt. % Gr		1.0 BHN			
Al6082 + 6wt. % Gr		30.2 BHN			
Al6082 + 9wt. % Gr		29.0 BHN			
Al6082 + 12wt. % Gr		28.3 BHN			

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